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Part I. Progress

STATUS REPORT ON THE SURF II FACILITY AT NBS

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The facilities and experimental program at SURF II (Synchrotron Ultraviolet Radiation Facility) are reported on. The planned upgrading of the storage ring and new beam lines are discussed.

1. Introduction

SURF II became operational in 1974 as a storage ring. Prior to that the instrument was a synchrotron and was used as such as a light source during the 1960s and early 1970s. The modification to a storage ring in 1974 utilized the original magnet iron, but virtually everything else was replaced.

The injection of electrons is performed by a 10 MeV microtron. The main magnets and correction coils are then ramped up to a field of about 1 T. This gives an orbital radius of 84 cm and an electron energy of 240 MeV. Typical stored currents are in the range of 10–25 mA. The single homogeneous magnetic field results in a well-defined beam size of the order of 0.1 mm height and 1.5 mm width. The geometry of the beam results in SURF being a very bright beam and with suitably designed monochromators gives useful radiation for a variety of purposes from about 50 Å to the visible. In addition, the stability inherent in a large single magnet and the circularity of the orbit makes SURF particularly useful for calibration and radiometric purposes, since the radiation can be accurately calculated.

The spectral output of SURF II is shown in fig. 1. The 250 MeV curve represents the flux as SURF is currently operated. Shortly after this conference SURF is shutting down for extensive remodeling. The main coils and correction coils are being modified/replaced along with new power supplies, which will result in SURF becoming a higher energy source, perhaps 280 MeV. This will not only allow for shorter wavelength opportunities but will increase the output in all spectral regions. In addition, a second rf cavity is being built to allow for introduction of higher harmonics and to incorporate the pulse bump coil. The net result will be to increase beam lifetime and to decrease bunch oscillation, which hinders injection [1]. George Rakowsky, the chief engineer, is responsible for effecting these changes.

Fig. 2 is a schematic of the experimental areas at SURF, showing the major aspects of the beam lines as presently developed. Two new stations have begun operation since the last report at this meeting: (1) NASA calibration chamber on beam line 2 (BL-2) and (2) the surface science chamber

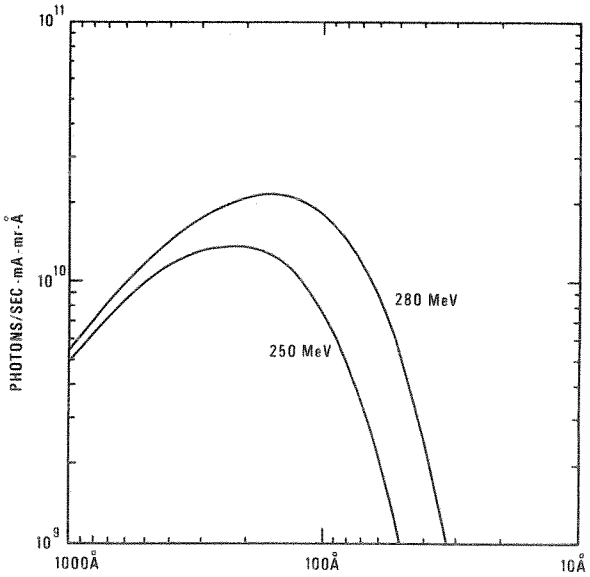

Fig. 1. Calculated flux curve for the radiation from SURF-II for 250 MeV and 280 MeV electrons. 280 MeV will be achieved upon completion of improvements during the summer of 1981.

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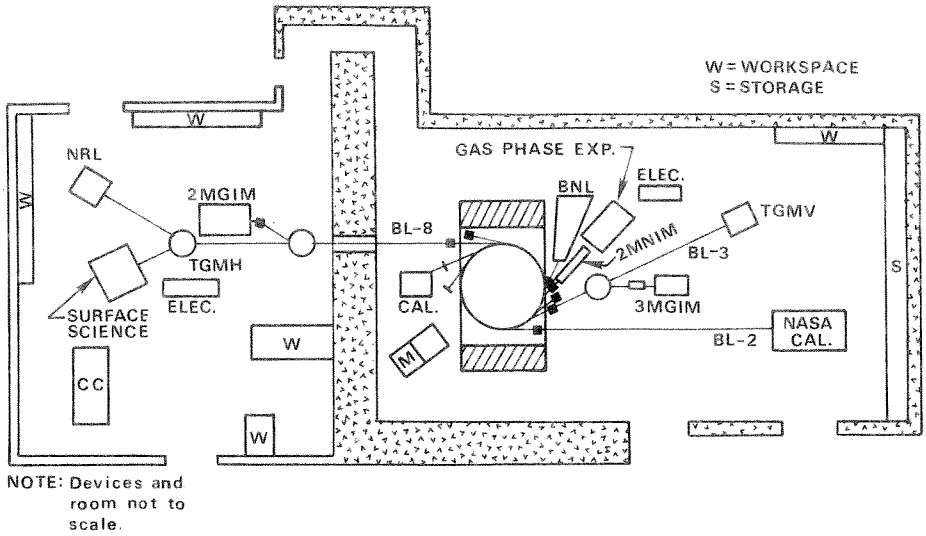

Fig. 2. Schematic diagram of the present experimental layout at SURF. Major additions have been the large NASA calibration chamber on BL-2 and the addition of the NBS surface science effort on BL-8. SURF has recently acquired a large room adjacent to the main experimental room for use in laboratory and operation functions.

on BL-8. These new facilities will be discussed in more detail.

2. Calibration facilities

Calibration techniques for the transfer photodiodes have been reviewed recently by Saloman et al. [2]. Beam line 3, with the vertical dispersion toroidal grating monochromator is used to calibrate photodiodes between 50 Å and 584 Å. These diodes, with cathodes of aluminum/aluminum oxide, are calibrated by referral to intensities measured by a rare gas double ionization chamber.

Lanny Hughey and Russ Schaeffer of NBS are working on an intercomparison of the measurement of the absolute flux as calculated from SURF and a separately calibrated silicon photodiode. The silicon photodiode used is of the type amenable to the self calibration technique. For use at the synchrotron a narrow band filter, of known transmission and an appropriate known optical connection to the storage ring vacuum, is used in conjunction with the photodiode.

The storage ring current can be accurately measured by using a photodiode with a built-in amplifier. This diode is capable of measuring on a unit basis the light from about 2000 electrons downward. Once the response for the light per electron is determined and the linearity of the dioded determined, then the normal beam currents of the storage ring can be measured accurately. If the number of electrons circulating in the storage ring is known precisely, then the absolute flux can be calculated from accepted theory [3]. This intercomparison will enhance SURF's use as an absolute radiometric source.

BL-2 has been fully developed for spectrometer calibration by the addition of a large movable vacuum chamber. Fig. 3 shows this chamber and beam line. The chamber is in the upper center of the photograph. The chamber is 1.2 m × 1.2 m × 2.5 m long. The whole chamber translates roughly 40 cm in x and y perpendicular to the beam direction. In addition, there is a 2-dimension gimbal inside the chamber that allows for angular control. The entire chamber positioning system is under computer control. These movements allow the transmission of spectrometers to be determined over their entire solid angle of acceptance and the transmission of telescopes to be determined over the whole area of the telescope aperture. As a result of SURF's known beam and calculable flux, users can be furnished with an absolute input flux known to within 5%. NASA helped sponser the construction of this chamber

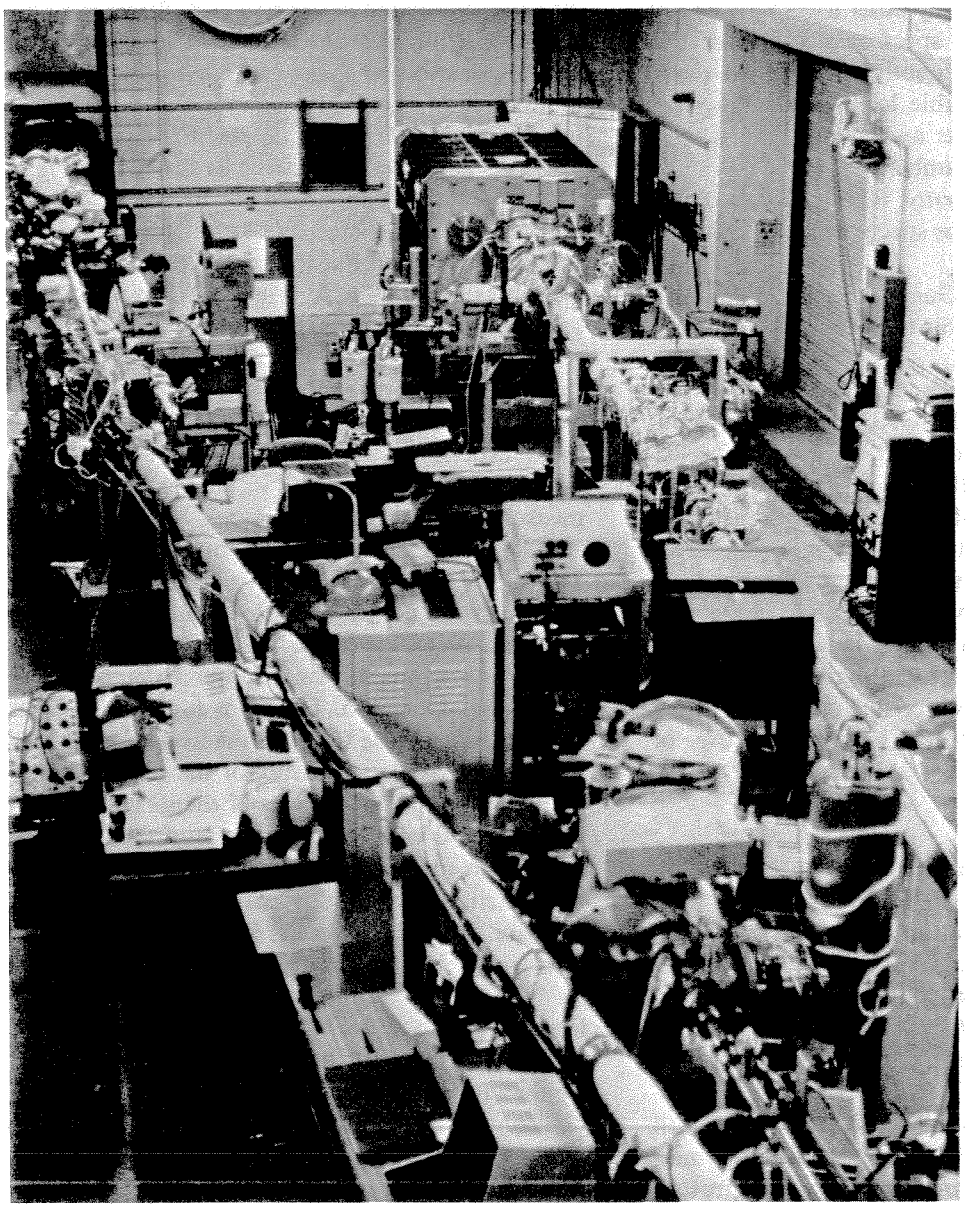

Fig. 3. Photograph of the main experimental room. The position of the large chamber is in the top center of the photograph. The entire chamber can be evacuated and then translated vertically and horizontally about 40 cm. A large gimbal inside allows for angular positioning of the instrument being calibrated.

for use in calibrating instruments which will fly on the space shuttle, and for other NASA-sponsored missions.

The large calibration chamber was brought on line in February 1981 and since that time has seen considerable use. The users and their objectives are listed below.

California Institute of Technology: Gordon Garmire and Norm Bobroff – 304° spectrometer for rocket flight, astrophysical application;

LASP, University of Colorado: G. Timothy and G. Mount – solar observation spectrometer;

Naval Research Laboratory: G. Brueckner and M.E. Van Hoosier – SUSIM (a shuttle spectrometer), 120–400 nm region for solar observations. In addition, BL-2 has been used without the large

chamber for calibration by other users who do not need to measure their spectrometer response in vacuum. For their use, another instrument manipulation stand is available having essentially the same x, y displacements and angular motions as the large calibration chamber.

Johns Hopkins University: R. Bell, J. Castracane and Bill Hodges – various spectrometers for plasma diagnostics;

NASA–Goddard: B. Guenter and D. Williams – sounding rocket spectrometers for solar observations.

The NASA calibration chamber is clean and vacuum compatible with SURF; hence, the instruments to be calibrated must be free of hydrocarbon contaminants that could compromise the optical performance of their own or other user systems, or migrate to the storage ring. This requirement and execution of the use of the facility are under the supervision of Bob Madden with technical support from Lanny Hughey and Steve Ebner. Steve Ebner is presenting a paper in the poster session at this conference on the details of the mechanical considerations and on the uses of the chamber.

3. Research facilities and efforts

New experimental stations have been developed by several groups. The NBS surface science project, under the direction of Roger Stockbauer and Ted Madey, has developed a versatile ultrahigh vacuum system for use on several monochromators available at SURF. The NRL group, consisting of Dick Williams and Jack Rife along with their associates from NRL, has developed a new chamber for use on the toroidal grating monchromator with horizontal dispersion (TGMH). A new experiment has been developed by the Argonne–NBS collaboration to study polarization of fluorescence during molecular photoionization. These programs will be described in more detail below, along with a discussion of ongoing efforts.

3.1. NBS surface science effort

The NBS Surface Science Division in a joint project with SURF has developed a new experimental chamber for studying photoion desorption, electron stimulated desorption and ultraviolet photoelectron spectroscopy (UPS). The chamber is entirely bakable and features a cylindrical mirror analyzer (CMA), sample manipulator, electron gun and associated electronics to perform Auger analysis. The apparatus schematic is shown in fig. 4. The CMA is normaly used for UPS, but can be alternately used to measure ion yield spectra and ion kinetic energy. For ion measurements the voltages are simply reversed. Time of flight techniques are employed to measure the mass of the ion [4].

Light is furnished by the TGMH on BL-8 or by the 2 m normal incident monochromator on BL-5. These two instruments give useful radiation for these experiments from about 180 Å to 1500 Å. The crystal can be cleaned in the vacuum and the measured exposures to gases can be made. Fig. 5 shows summary results for Ti, oxidized at various exposures. The rate of oxygen ion desorption changes with coverage, with an increasing yield with increasing coverage. This is presumably due to decreasing metal bonding per oxygen site as coverage is increased. The work function changes correspond to those found in the literature [5]. The Auger intensity is a measure of the oxygen coverage. The general conclusions of the ion desorption are in accord with the predictions of the Knotek–Feibelman mechanism [6], which in this case suggests excitation of a Ti 3p core hole with resulting electron loss, which results in formation of O^+. This group has performed similar measurements on Nb, and the results are to be reported in the literature.

These efforts have been substantially promoted by the efforts of the present SURF Fellow David Hanson of SUNY, Stony Brook and Guest Worker Anders Flödström of Linköping University in Sweden.

3.2. NRL – BL-8

The NRL group, including Dick Williams, Dave Nagel, Milt Kabler and a recent addition, Jack Rife, has had a substantial effort at SURF over the last several years. Their work has included measurements of the reflectivities and fluorescent yields of CaF_2 [7] and BeF_2 [8] and more recently they have developed techniques to study photoemission from multiphoton, multicolor photon absorption in semiconductors. The multiphoton experiments involve excitation of valence level

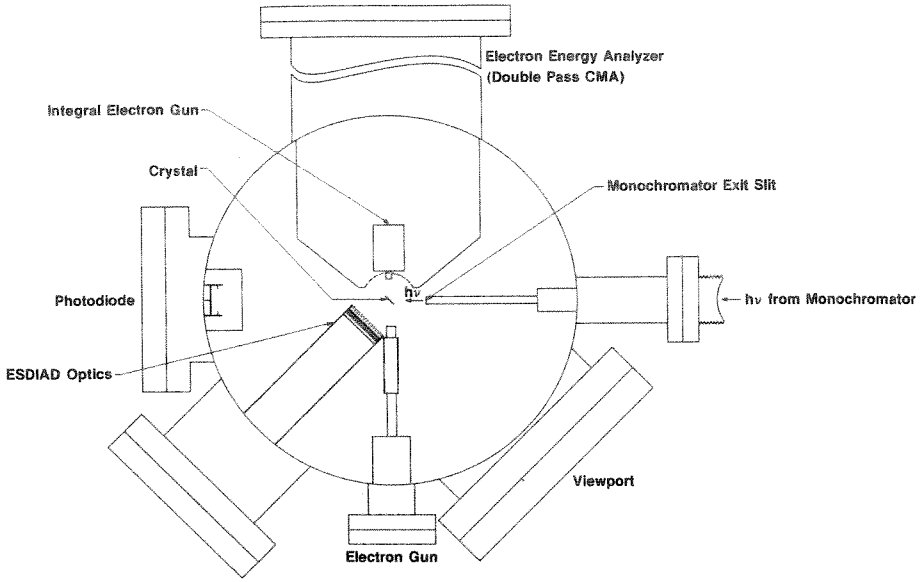

Fig. 4. Diagram of the NBS surface science chamber showing the salient features which include a cylindrical mirror analyzer (CMA), electron gun and electron stimulated desorption ion angular distribution optics (ESDIAD). The electronics on the CMA are such that it can be used to measure ion kinetic energies as well as mass with time of flight techniques. The chamber is a bakable ultrahigh vacuum chamber and routinely achieves pressures in the low 10^{-10} Torr range.

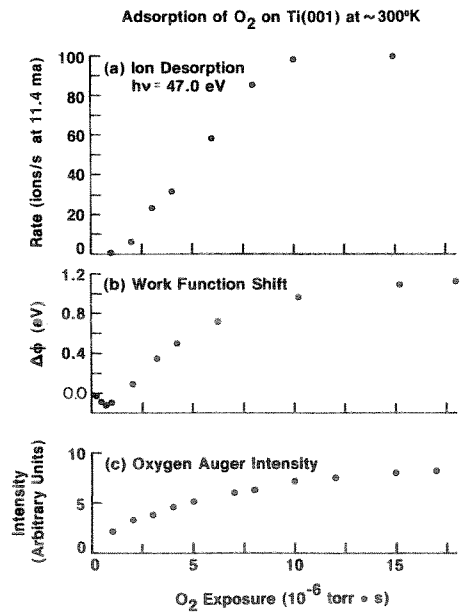

Fig. 5. Changes in (a) the photon stimulated desorption, (b) the work function and (c) the KLL Auger intensity caused by exposure of the Ti(001) surface to increasing amounts of oxygen. The data for the PSD yield are normalized to a storage ring current of 11.4 mA which produces a photon flux onto the sample of 2.83×10^9 photon/s at 47 eV. The measured yield is for detected ions and is better than 20% of the total yield.

electrons to empty conduction band states or surface states which are below vacuum level. These excited states in turn are probed via the absorption of another photon, which results in photoemission. The electron kinetic energy distributions are measured with a CMA [9].

Jack Rife and his collaborators, Steve Donnelly, J.N. Gilles and A.A. Lucas of IRIS in Namur, have developed techniques for ascertainting the density of He in microbubbles in metals. They used the Rowland circle 2.2 m station on BL-8 for these measurements, which were essentially transmission spectra [10].

3.3. Howard University–Goddard – 2.2 m instrument

Bob Catchings of Howard University is using the 2.2 m grazing incidence instrument to measure the optical constants of glass materials in the 70 Å to 300 Å region. The reflection is measured as a function of angle and polarization and the optical constants are deduced. The measurements are being made on low coefficient of expansion quartz and borosilicate glass. Dr. Catchings is working with John Osantowski of Goddard on this project.

3.4. BL-6 – Brookhaven circular dichroism

John Sutherland along with Peter Takacs and Peter Keck have developed a circular dichroism spectrometer for use in the vacuum UV. This instrument was described in the Proceedings of the 1979 conference in this series [11]. Their work involves the study in solution of the circular dichroism (CD) in large biochemical molecules. Recent work on Z-DNA, among other things, indicates that the VUV CD is sensitive to the handedness of the helical structure of the molecule [12]. This experiment will be transferred to BNL when facilities become available there.

3.5. BL-5 – 2 m normal incidence monochromator

This station has, since its beginnings shortly before the last conference, been very productive and greatly utilized. The gas phase triply differential photoelectron spectrometry experiment first described at the last meeting of his conference has been improved with additional magnetic shielding and an improved light detection device [13]. This monochromator has also been used for new experiments in fluorescence polarization spectrometry, by the NBS surface science group for low energy photoemission and ion desorption studies, for Stark effect measurements in the VUV and by NRL for the two photon excitation experiments.

Variable wavelength photoelectron spectometry: A two inch mean radius hemispherical electron energy analyzer is rotated in a magnetically shielded chamber. At a particular wavelength scans of photoelectron energy distributions are made at two or more angles. The results of such a measurement are shown in fig. 6 for O_2 in a window absorption region. Note that the various vibrational levels of the ground ionic state have different values of the asymmetry parameter. The differential cross sections for a photoabsorption process can be written:

$$\frac{d\sigma_v}{d\Omega} = \frac{\sigma_v}{4\pi}\left[1 + \frac{\beta}{4}(3P\cos 2\theta + 1)\right],$$

where β = asymmetry parameter, P = polarization of light and θ = angle between electron ejections and polarization of light. The number of electrons as a function of angle is determined, and β and the branching ratios (relative amplitudes of the vibrational transitions) are determined. The results of a typical experiment are shown in fig. 7, which show the variation in β for molecular nitrogen in its ground ionic state as the wavelength is stepped through a window and absorption series in the 710 Å to 730 Å region. The simple models of molecular photoionization would predict a smooth β as a function of wavelength and β would be independent of vibrational excitation. This example and a wealth of other data gathered on this experiment address the issue of the effects of resonance phenomena in molecular photoionization [14]. This user group has consisted of Parr and Ederer of the SURF staff, Roger Stockbauer of the NBS Surface Science Division, Joe Dehmer of Argonne, John West of Daresbury and Keith Codling of Reading University. Recently David Holland, from Reading University, has joined this group. The angular calibration of the photoelec-

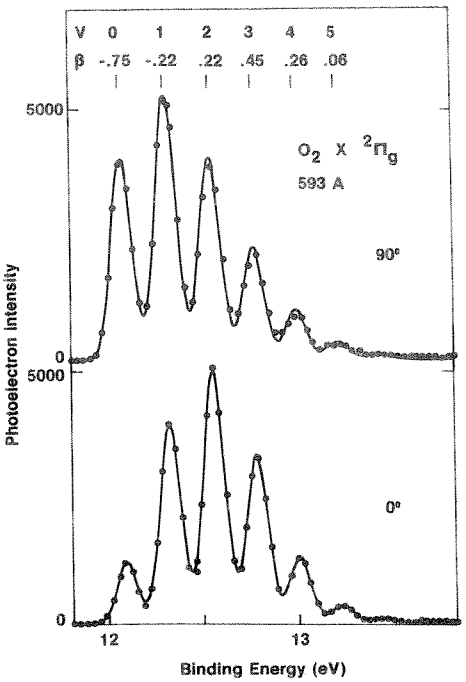

Fig. 6. Photoelectron spectrum of O_2 in a window resonance region at 593 Å. The ion is left in the ground state. The horizontal scale is electron kinetic energy, adjusted by the ionization potential to show the binding energy. Two spectrum are shown, one at 0° with respect to the polarization of the light and the other representing electrons collected at 90° with respect to the light. The dots are experimental data and the solid lines are a computer fit curve. The relative intensities of the various vibrational levels change with angle indicating a varying asymmetry parameter.

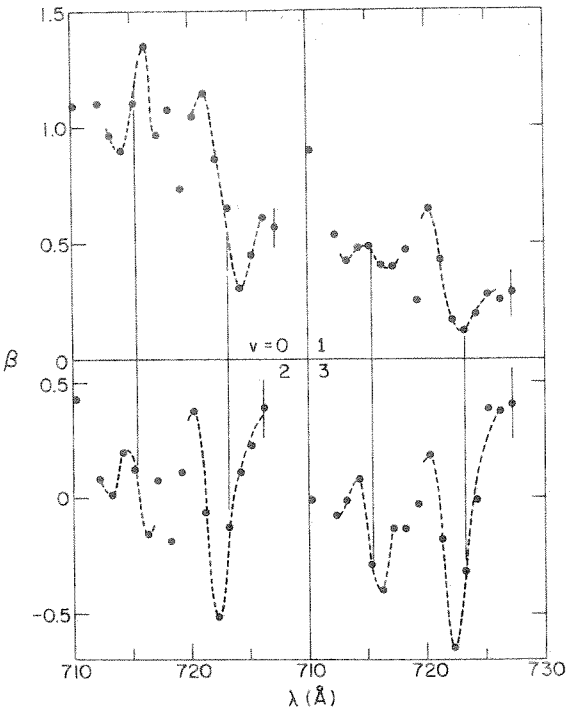

Fig. 7. The asymmetry parameter for the first four vibrational levels of molecular nitrogen during ionization which leaves the molecule ion in the ground state. This wavelength region in nitrogen has a window and absorption series which autoionize. The changes in β in this region reflect the influence of the autoionization upon the ionization process.

tron spectrometer is the subject of a paper by Holland at this conference.

Fluorescence polarization spectroscopy: Fig. 8 shows the schematic of a new experiment at SURF designed at Argonne National Laboratory by Erwin Poliakoff and Joe Dehmer. The apparatus as shown in the figure is enclosed in a large magnetically shielded chamber pumped by closed cycle helium cryopumps.

Excited state molecular ions are formed via photoionization and the polarization of their subsequent decay is measured with the apparatus shown. The polarizer, shutter and monochromator are controlled by a Camac based LSI-11 computer system. The system is calibrated against intrinsic polarization bias with a known isotropic light source.

The results for the photoexcitation of the N_2^+ $B^2\Sigma_u^+$ state fluorescence are shown in fig. 9. The solid lines are theoretical curves from a calculation for various rotational levels. The upper part of the

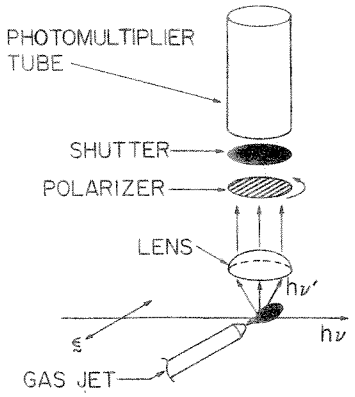

Fig. 8. Schematic diagram of the apparatus used to study the polarization of fluorescence during molecular photoionization. The polarizer, shutter and photomultiplier are mounted external to the vacuum system. The polarization of the light is represented by →.

figure is a comparison of the ratios of dipole matrix elements for the π_g and σ_g channels as deduced from measuring the polarization P of the fluorescence radiation. The experimental results are compared to theory. This measurements then allows for a determination of the relative photoionization strengths of the π_g and σ_g channels of

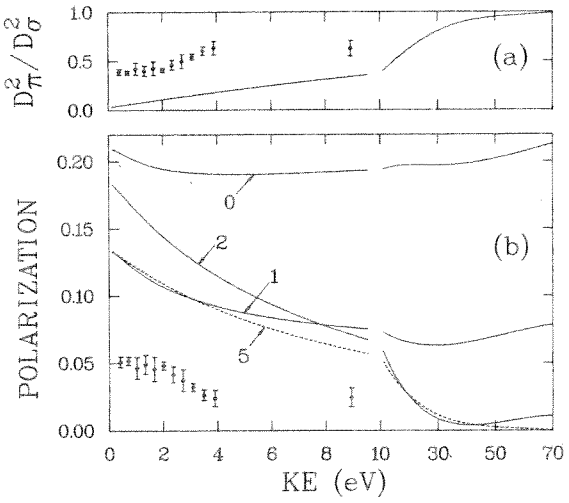

Fig. 9. The polarization of fluorescence (b) as a function of electron kinetic energy as measured for formation of the $B^2\Sigma_u^+$ state of N_2 at 18.757 eV. The scale breaks at 10 eV. The solid curves are theoretical results for initial values of rotational levels as indicated. The upper portion of the figure (a) shows the derived ratio of the dipole matrix elements $D\pi$ and $D\sigma$ for the π and σ outgoing channels for the electron. The solid line is the calculated result. See ref. 15 for details.

the outgoing electron. These channels are energetically degenerate and cannot be separated by photoelectron spectroscopy.

Modifications to this experiment are underway to enhance sensitivity and to perhaps add wavelength selectivity on the detection channel. The results of the preliminary experiment are reported in the literature [15].

3.6. BL-3 – high resolution grazing incidence spectrograph

A stark effect adsorption cell of about one meter length containing field plates of about 1/8″ separation has been placed in front of the spectrograph. A high voltage is applied and changes in the absorption spectra are noted. Fig. 10 shows such data for Ar as a function of electric field and wavelength. The top curve is the theoretical apparent cross section. This curve is prepared by taking known oscillator strengths in the region below the $P_{3/2}$ limit and convoluting with the instrumental function. As these levels field ionize and lose their discrete nature, the structure as shown is observed [16]. This work and other work on metal vapor absorption is carried out by E.B. Saloman of the SURF staff, J.W. Cooper of the Center for Absolute Physical Quantities at NBS and Guest Worker C. Mehlman.

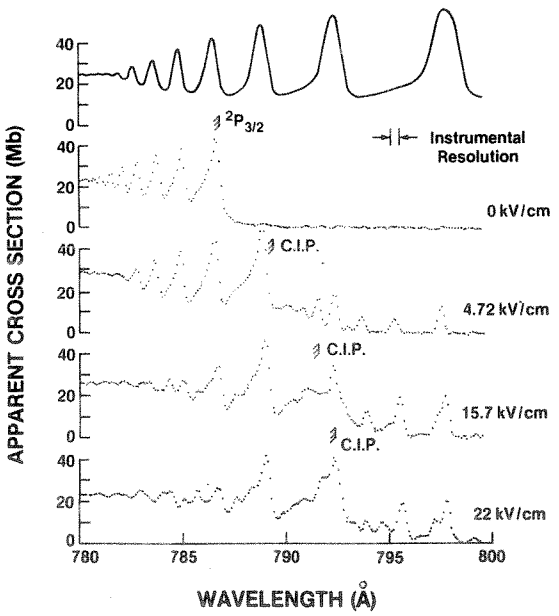

Fig. 10. Absorption cross section for argon near the ionization limit in the presence of various applied electric fields. The top curve is a theoretical calculation for an apparent cross section obtained by convoluting instrumental parameters to the discrete structure below the ionization limit.

4. New instruments being planned

High flux grazing incidence: A new toroidal grating instrument specifically designed for SURF and optimized for throughput has been designed. This instrument is the subject of a paper by Stockbauer and Madden at this conference. Briefly, the instrument will have a flux output in the 150 Å to 600 Å region, which will be comparable to the 2 m normal incidence instrument. The mid-range resolution will be about 6 Å at high flux, but by stopping down the aperture, a higher resolution can be obtained.

This monochromator will be used on the gas phase experiments and for the NBS surface science effort. The location of this monochromator is to be on BL-1, which will place the instrument's exit slit about 2 m above the floor between BL-2 (NASA calibration chamber) and the near wall. Depending upon funding and experimental needs, possibly two of these instruments will be built.

New photoelectron spectrometer: A completely new photoelectron spectrometer experiment is being built. A new, larger (30″ diameter 36″ long) magnetically shielded chamber is being constructed which will house a rotatable 4″ mean radius hemispherical electron energy analyzer. Improved pumping, detection and optics will given a significantly enhanced instrument with new capabilities.

References

[1] G. Rakowsky, IEEE Trans. Nucl. Sci. NS-28 (1981) 1519.
[2] E.B. Saloman, S.C. Ebner and L.R. Hughey, SPIE Symposium no. 279, to be published July 1981; see also E.B. Saloman, Nucl. Instr. and Meth. 172 (1980) 74.
[3] J. Schwinger, Phys. Rev. 75 (1949) 1912.
[4] D.M. Hanson., R.L. Stockbauer and T.E. Madey, submitted to Phys. Rev. B.
[5] Y. Fukuda, W.T. Elam and R.L. Park, Appl. Surf. Sci. 1 (1978) 278.
[6] M.L. Knotek and P.J. Feibleman, Phys. Rev. Lett. 40 (1978) 964.
[7] R.T. Williams, D.J. Nagel and M.N. Kabler, Jour. de Phys. 41 (1980) C6-439.

[8] R.T. Williams, D.J. Nagel, P.H. Klein and M.J. Weber, submitted to J. Appl. Phys.
[9] R.T. Williams, J.C. Rife, T.R. Royt and M.N. Kabler, submitted to J. Vac. Sci. Tech.
[10] S.E. Donnelly, J.C. Rife, J.M. Gilles and A.A. Lucas, J. Nucl. Mat. 93 (1980) 767.
[11] J.C. Sutherland, E.J. Desmond and P.Z. Takacs, Nucl. Instr. and Meth. 172 (1980) 195.
[12] J.C. Sutherland, K.P. Griffin, P.C. Keck and P.Z. Takacs, PNAS, in press.
[13] A.C. Parr, R. Stockbauer, B.E. Cole, D.L. Ederer, J.L. Dehmer and J.B. West, Nucl. Instr. and Meth. 172 (1980) 357.
[14] See for example: A.C. Parr, D.L. Ederer, B.E. Cole, J.B. West, K. Codling and J.L. Dehmer, Phys. Rev. Lett. 46 (1981) 22.
[15] E.D. Poliakoff, J.L. Dehmer, D. Dill, A.C. Parr, K.H. Jackson and R.N. Zare, Phys. Rev. Lett. 46 (1981) 907.
[16] B.E. Cole, J.W. Cooper and E.B. Saloman, Phys. Rev. Lett. 45 (1980) 887.